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# The Impact of Advances in Pre- and Post-Combustion $CO_2$ Capture Technologies for Coal-fired Electric Power Generation

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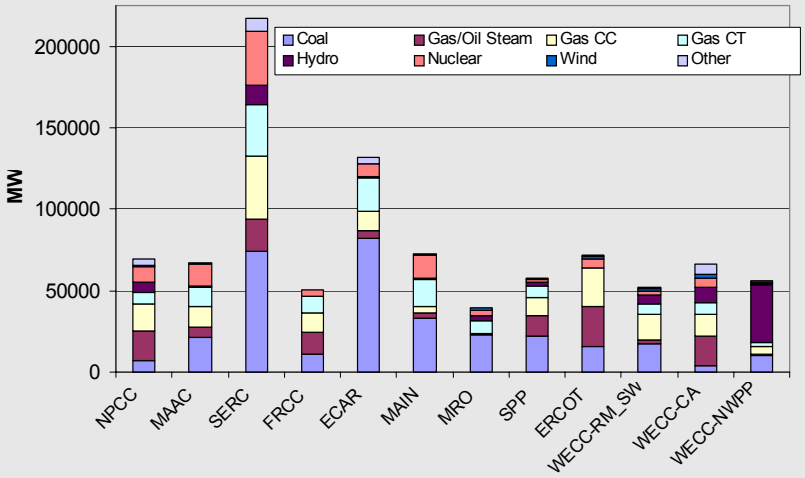
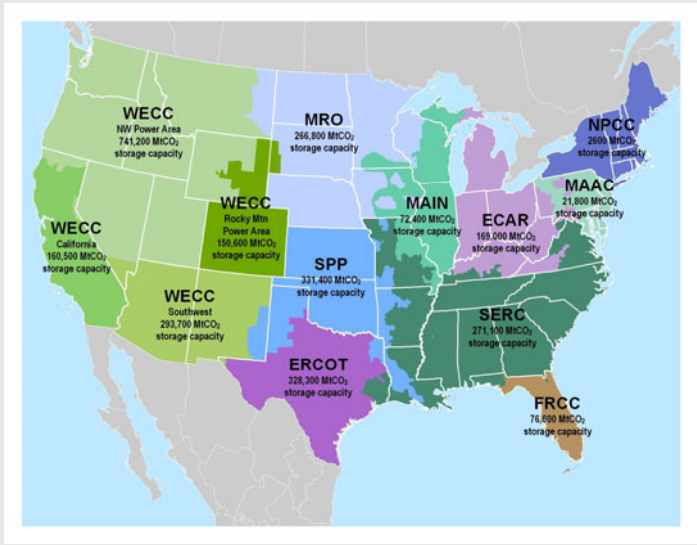
# Motivation

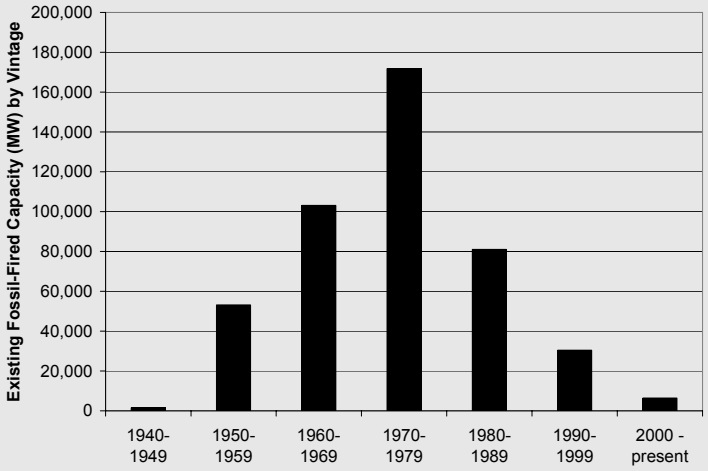
- Recently-published study of economic penetration of CCS.
  - Wise, M.A. J.J. Dooley, R Dahowski, C. Davidson. 2007. Modeling the Impacts of Climate Policy on the Deployment of Carbon Dioxide Capture and Geologic Storage across Electric Power Regions in the United States. *International Journal of Greenhouse Gas Control*. Volume I. Elsevier. www.elsevier.com/locate/ijggc.

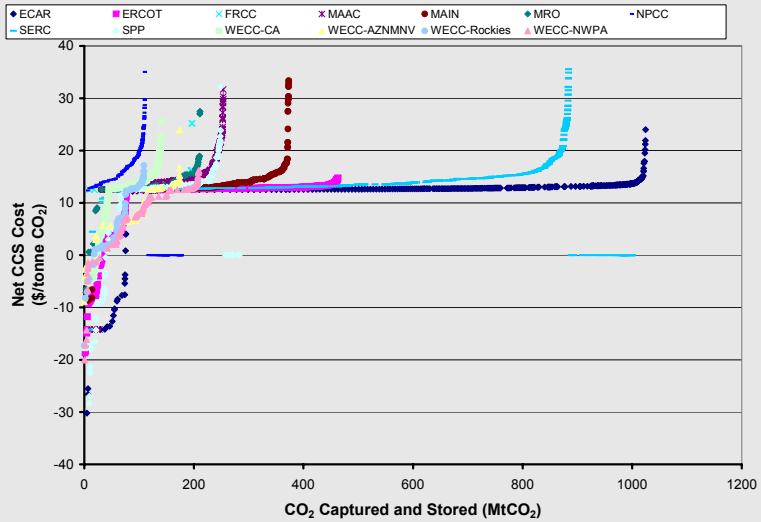
- In that paper we showed that under certain climate policies:
  - Most NERC regions begin significant (greater than 10,000 MW) deployment of IGCC+CCS power systems between 2020-2040
  - By 2045, most of the NERC regions have substantially decarbonized their baseload generation
    - Between 180 and 580 gigawatts (GW) of IGCC+CCS built by 2045
    - Between 12 and 41 $GtCO_2$ stored in deep geologic reservoirs by 2045
    - Only at the high carbon prices did we see any PC+CCS retrofits
  - Simply knowing whether a given region has more theoretical $CO_2$ storage capacity or more "value-added" $CO_2$ storage potential tells us only one small determinant of when and where CCS-enabled electric generation capacity will be built and operated

# The heterogeneity of current regional electric generation systems and regional $CO_2$ storage characteristics must be taken into account

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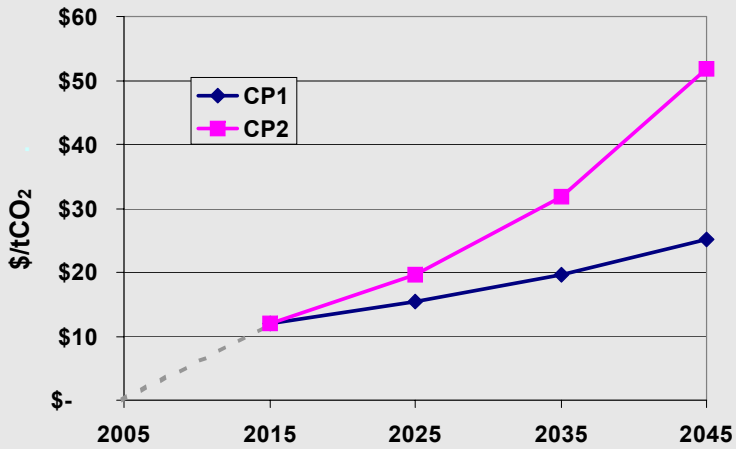
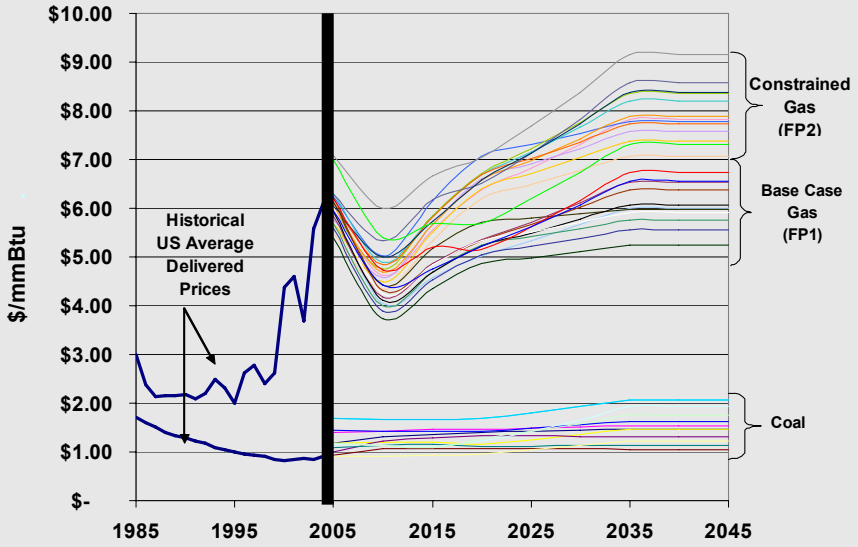
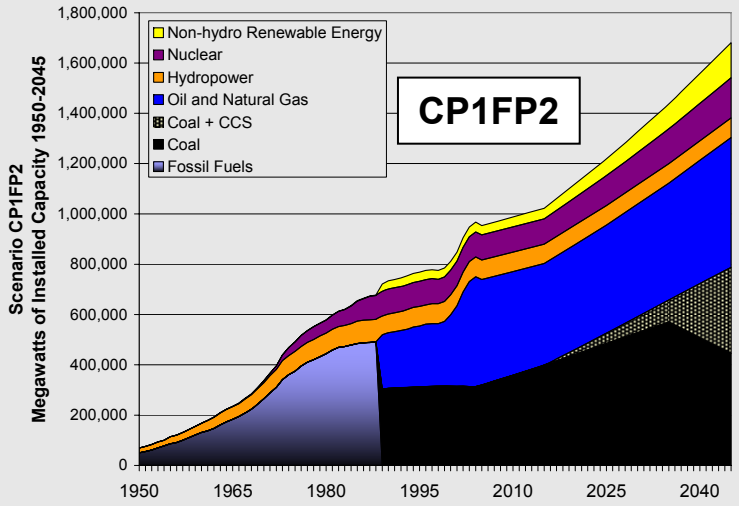
# In Wise, et al 2007: Four Modeled Energy and Climate Policy Scenarios

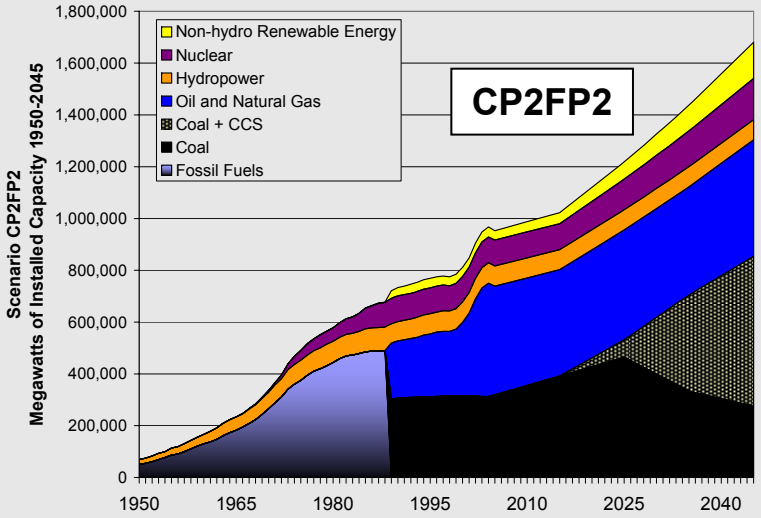
- **CP1FP1** (Carbon Permit Price 1, Fuel Price 1):
  - Carbon price is applied uniformly across the electric power sector
  - Carbon policy is announced in 2006 with implementation to start in 2015 at \$12/ton $CO_2$ and rise in real terms at 2.5% per year
  - Regional delivered coal and natural gas prices for this scenario correspond to the Energy Information Administration's (EIA) 2005 Annual Energy Outlook's Reference Case
- **CP1FP2** (Carbon Permit Price 1, Fuel Price 2):
  - This scenario assumes the same CP1 carbon prices
  - Energy prices are from the EIA's Constrained Supply Case.
- **CP2FP1** (Carbon Permit Price 2, Fuel Price 1):
  - Electric sector carbon price that is announced in 2006 with implementation to start in 2015
  - Carbon price starts our at \$12/ton $CO_2$ and escalates at 5% per year (reaching \$52/ton $CO_2$ in 2045)
  - Same fuel prices as in CP1FP1
- **CP2FP2** (Carbon Permit Price 2, Fuel Price 2):
  - This scenario combines the CP2 carbon price path with the higher FP2 natural gas prices.

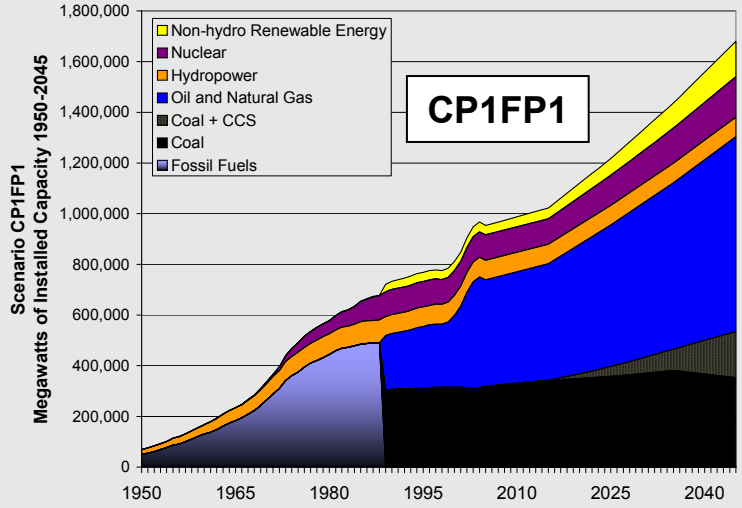


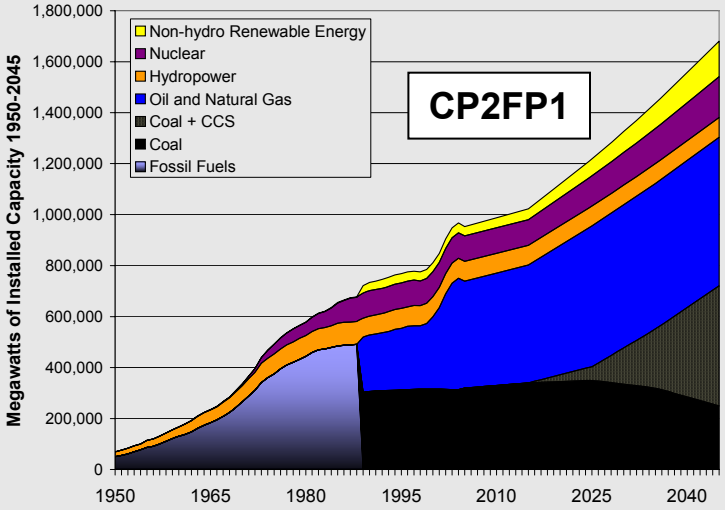



# US Electricity Generation Substantially Decarbonized Across Four Scenarios




Increasing Natural Gas Prices

Increasing $CO_2$ Permit Prices

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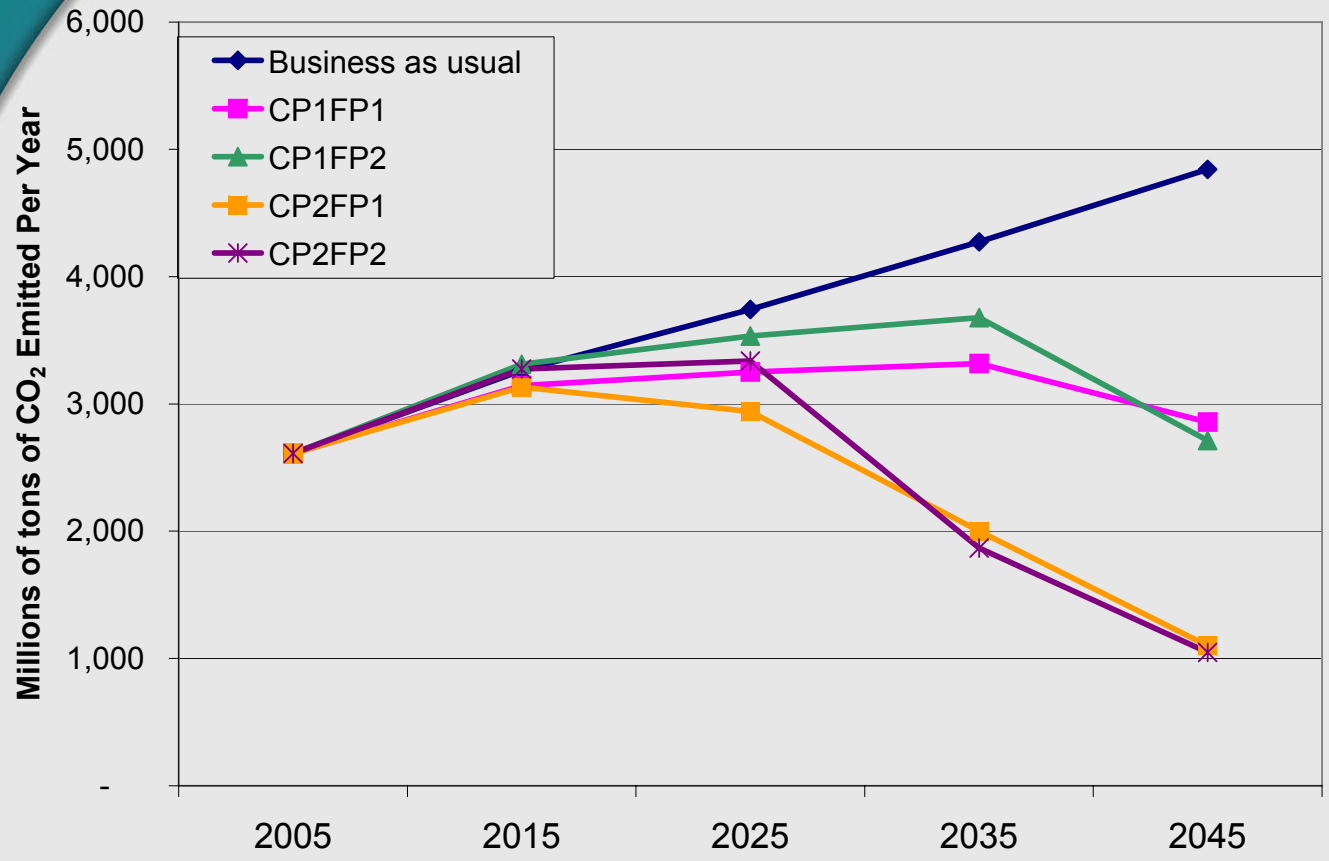
# Resulting USA Electric Sector $CO_2$ Emissions




180-580 GW of coal-fired CCS capacity installed 2005-2045

By 2045, utility sector emissions are 41-78% lower than the "business as usual" reference case

# Study Approach and Key Assumptions about Future Electric Capacity

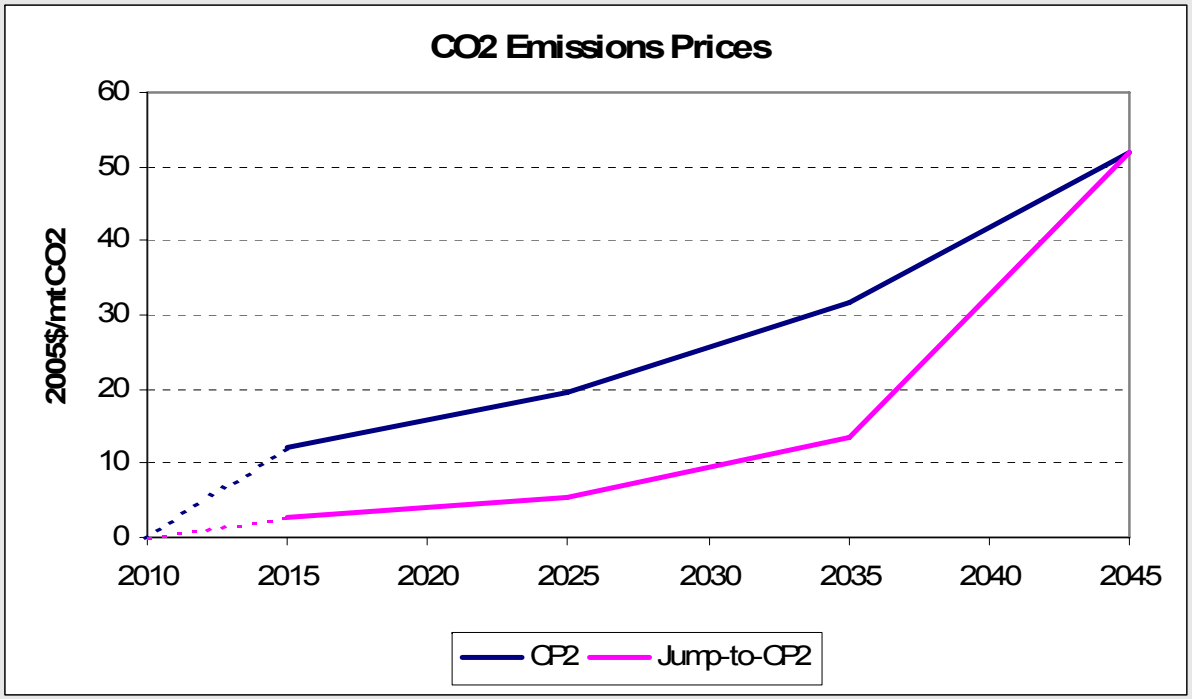
- Model the impact of technological improvements in PC+CCS systems under hypothetical $CO_2$ emissions policies out to 2045.
  - Also assume the IGCC+CCS technology is successful and improves as in the Wise, et al 2007 study.
  - Future improvements in PC $CO_2$ capture systems taken from Rao, Rubin, et al. 2006.
    - **Base PC+CCS**: Baseline technology approximately $47/ton $CO_2$ avoided
    - **Improved PC+CCS**: "Optimistic" case of 35% reduction in cost of avoided $CO_2$. (e.g., to about $31/ton $CO_2$ avoided at a given capacity factor)

- Options for new electric generating capacity include new pulverized coal (PC), IGCC, and gas CC, each with an option for CCS (either when built or later as retrofit). Gas CTs for peaking.
  - Retrofit of existing PC to CCS is also considered, as are economic retirements of all types of plants.
  - Capital costs, efficiencies, and operating and maintenance costs of new plants from EIA AEO 2005 and David and Herzog (2000).
  - To be conservative in terms of potential deployment of CCS, we assume substantial growth in nuclear and renewable power.

- ECAR demand growth starts at 1.9% per year (from FERC filings) and is assumed to taper downwards to 1.4%/year by 2045.

# Four Scenarios: Two PC+CCS Cases with Two $CO_2$ Emissions Price Paths

- Two PC+CCS technology cases (after Rao, et. al, 2007):
  - **Base PC+CCS**: Baseline technology approximately \$47/ton $CO_2$ avoided
  - **Improved PC+CCS**: "Optimistic" case of 35% reduction in cost of avoided $CO_2$. (\$31/ton $CO_2$ avoided)



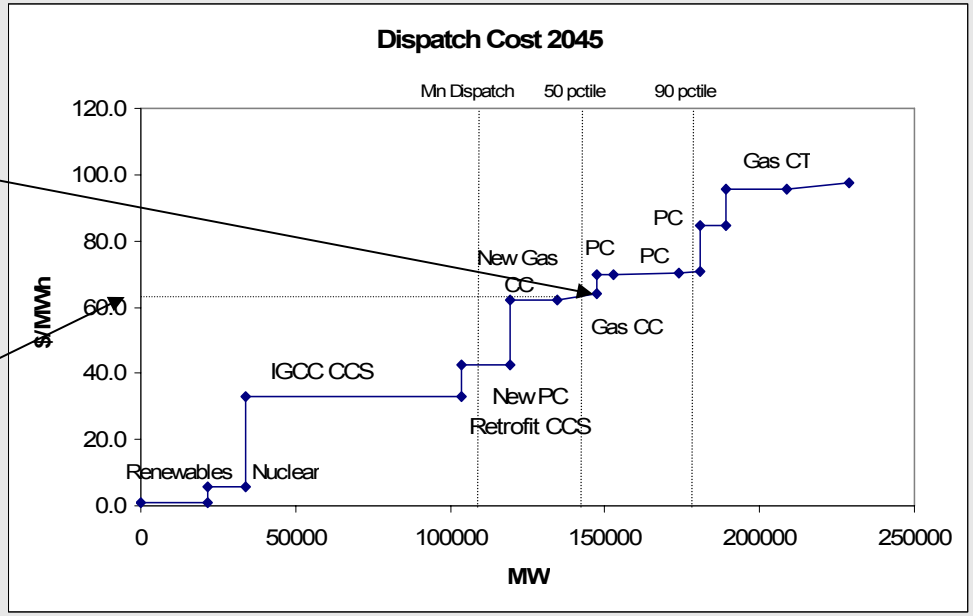

- Two $CO_2$ emissions price paths.
  - **CP2**: Smooth path. Starts at \$12/ton $CO_2$ and escalates at 5% per year.
  - **Jump to CP2**: Starts lower and grows smoothly until system is "surprised" by a sudden policy to increase price to CP2 level by 2045.

# Electricity Generation Dispatch Curves

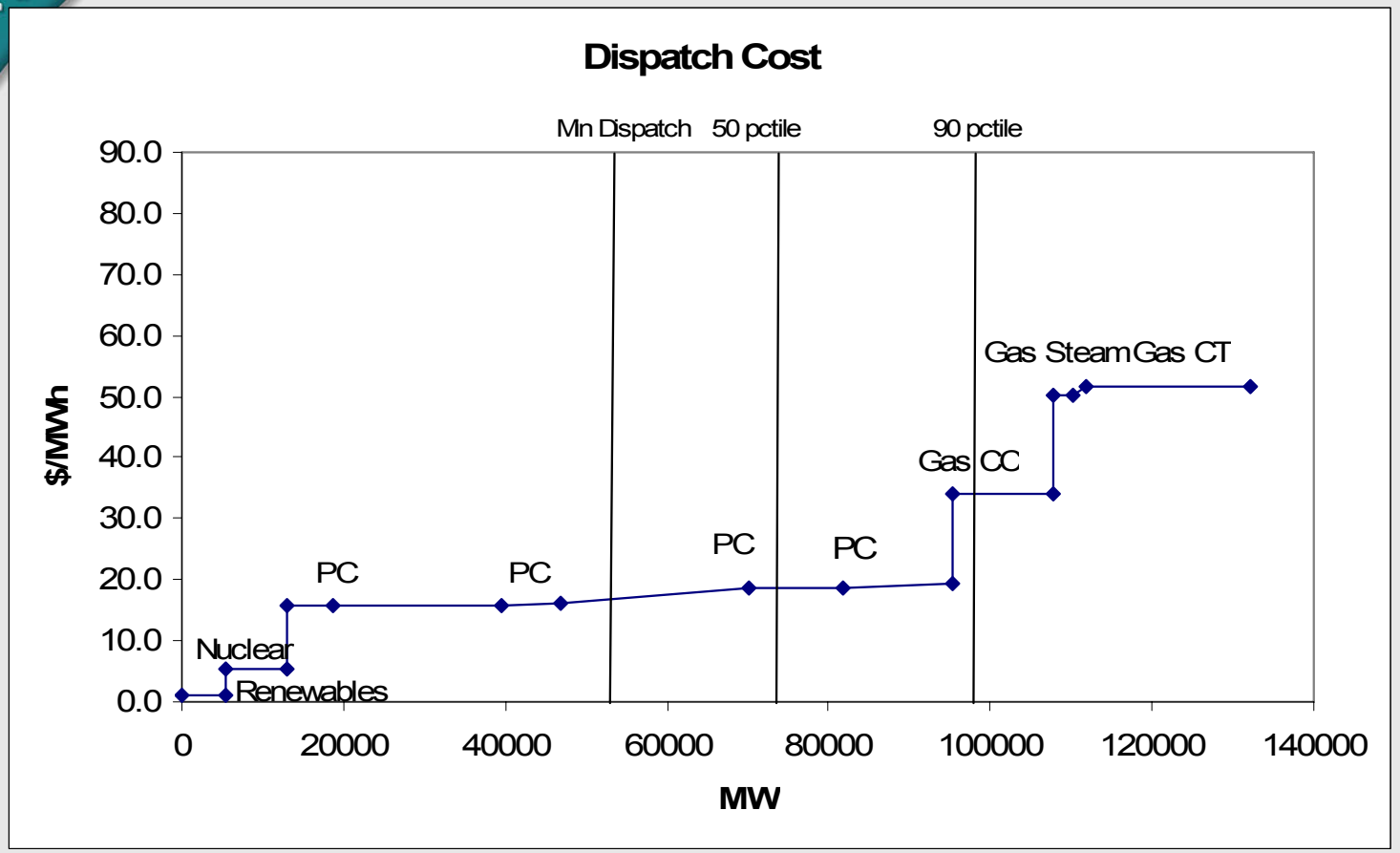
- An electricity generation dispatch curve is a plot of the dispatch cost (fuel and other variable operating costs) on the vertical axis versus the cumulative amount of capacity available at each dispatch cost on the horizontal axis.
- Dispatch curves provide an extremely useful depiction of the capacity mix in a manner that provides insight into capacity factors (how much a plant operates) and electricity prices.

With load (or demand) levels plotted as vertical lines on the supply curve – all capacity to the left of each load level is economical to dispatch at that load level.

And the short-term price at that point is also set by the dispatch cost at that load level.

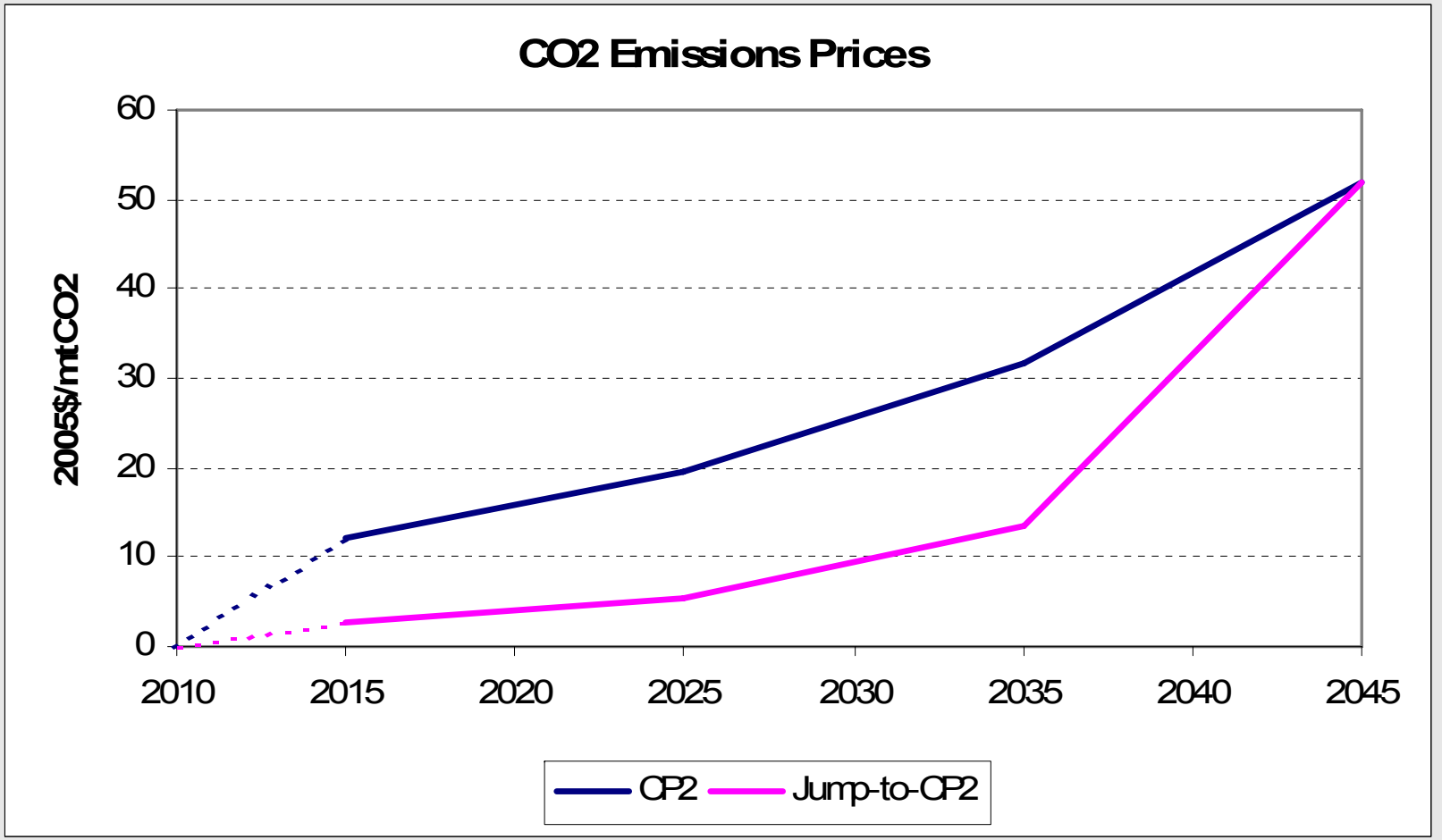


# ECAR: 2005 Dispatch Curve



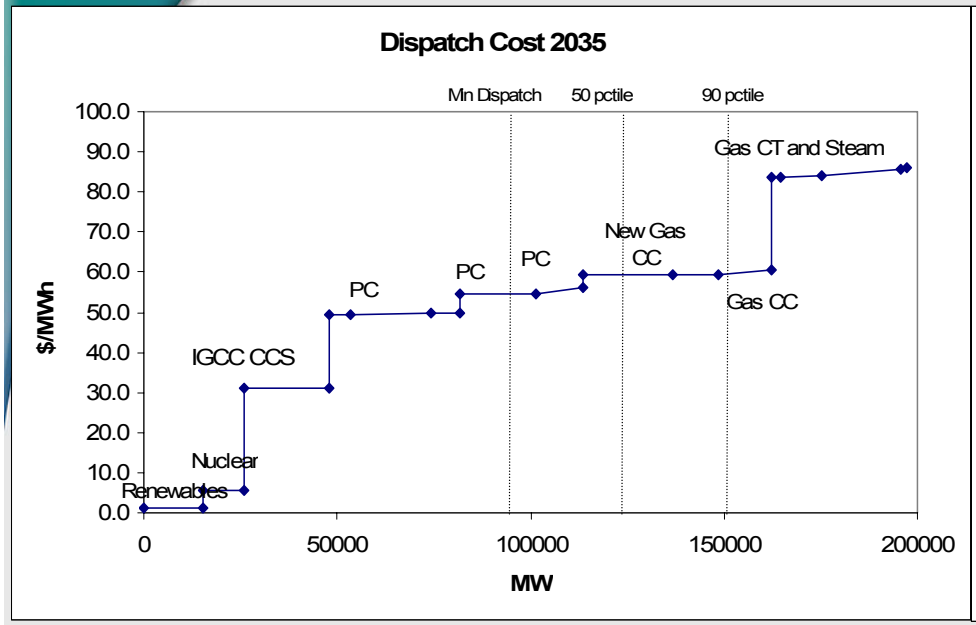

- ECAR's capacity mix has long been dominated by coal plants.
- Small amount of nuclear compared to its neighboring NERC regions.
- Recent build-up of gas combined cycles (CCs).

# Smooth CP2 and Jump to CP2



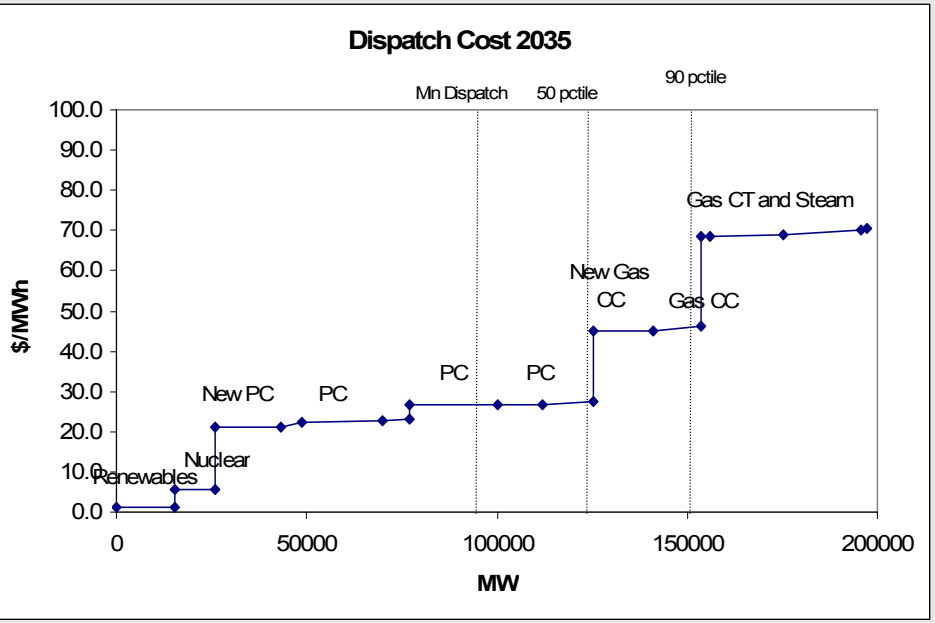
# ECAR 2035: Improved PC Capture Technology under the two Different $CO_2$ Price Paths

## Improved PC+CCS, CP2 CO2 Price Path




- With the smoothly growing CP2 $CO_2$ price path in place, new IGCC+CCS already built by 2035.
- No new PC is built, but most existing PC still serves as baseload.
- Although PC is baseload, its margin (price minus cost, compare to gas cost on curve) is much reduced by the $CO_2$ price.

## Improved PC+CCS, Jump to CP2 CO2 Price Path




- With lower $CO_2$ prices, and no knowledge of future higher $CO_2$ prices to come, about 18 GW of new PC is built by 2035.
- With the lower $CO_2$ price, PC earns a higher margin versus the gas capacity that is setting the electricity price half the time

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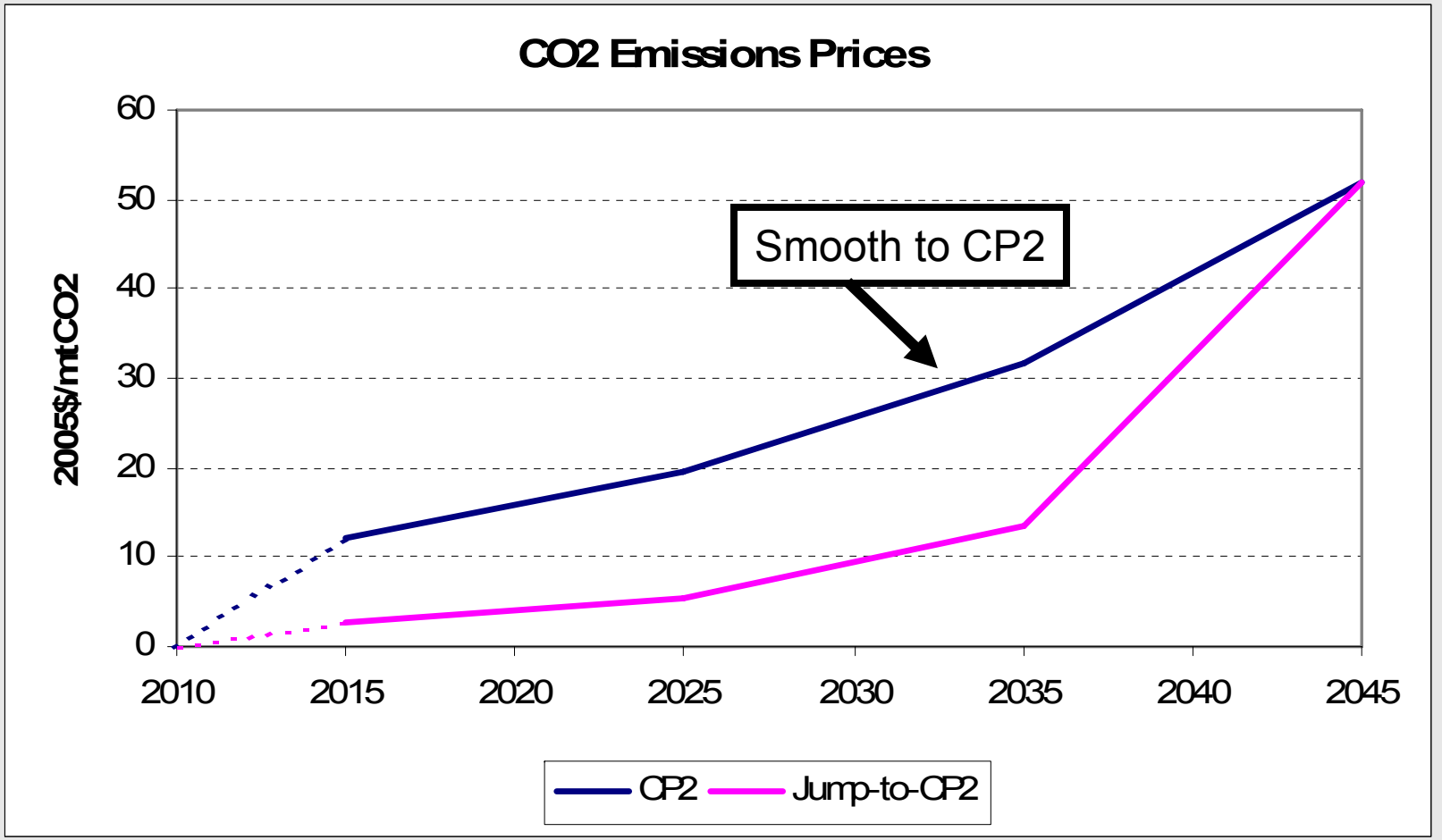
# Smooth CP2 and Jump to CP2

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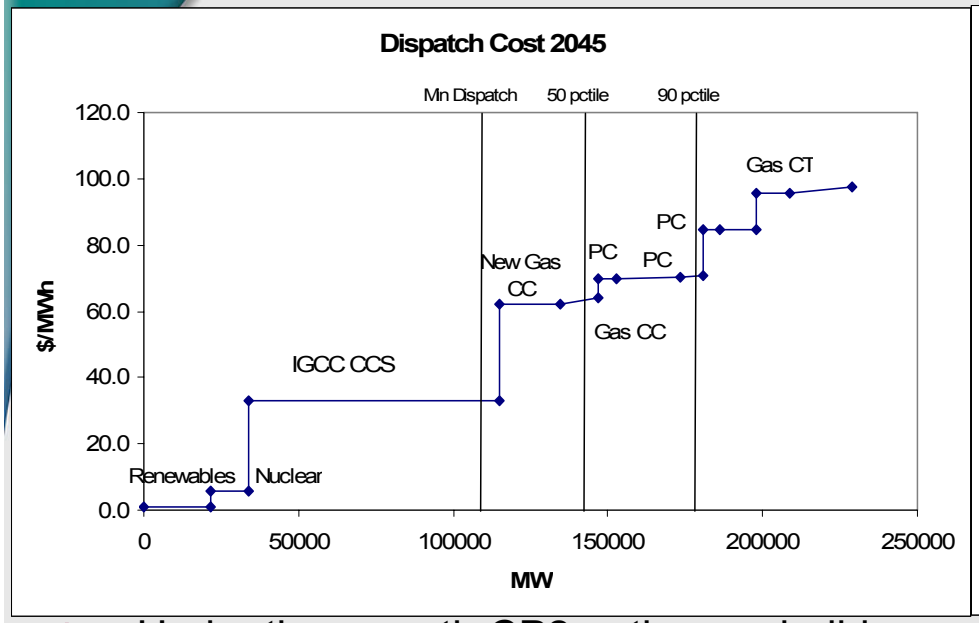
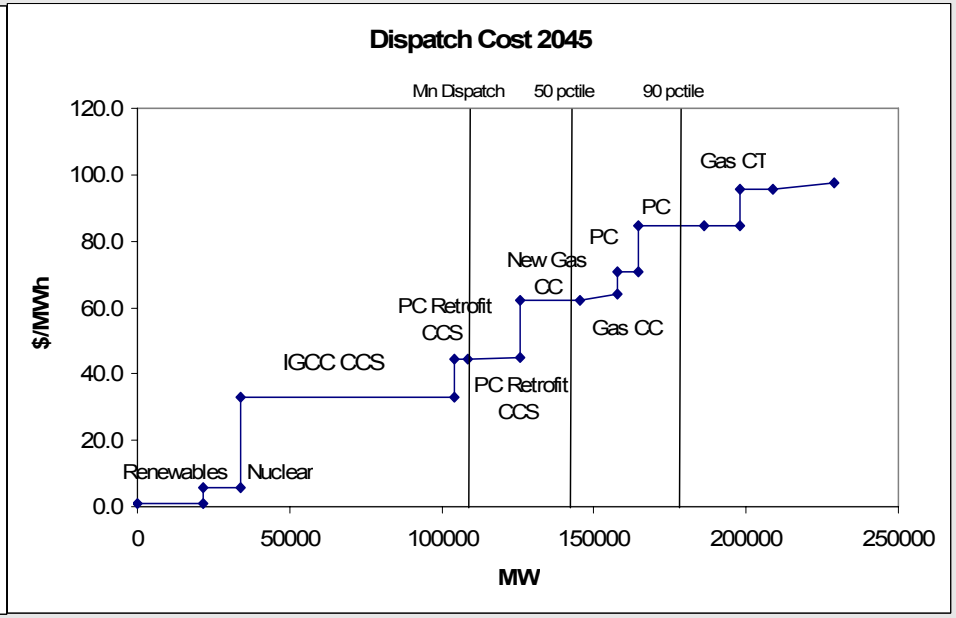
# ECAR 2045: Smooth $CO_2$ Price Paths
# Base PC Capture Tech vs. Improved PC+CCS

## Base PC+CCS, CP2 CO2 Price Path



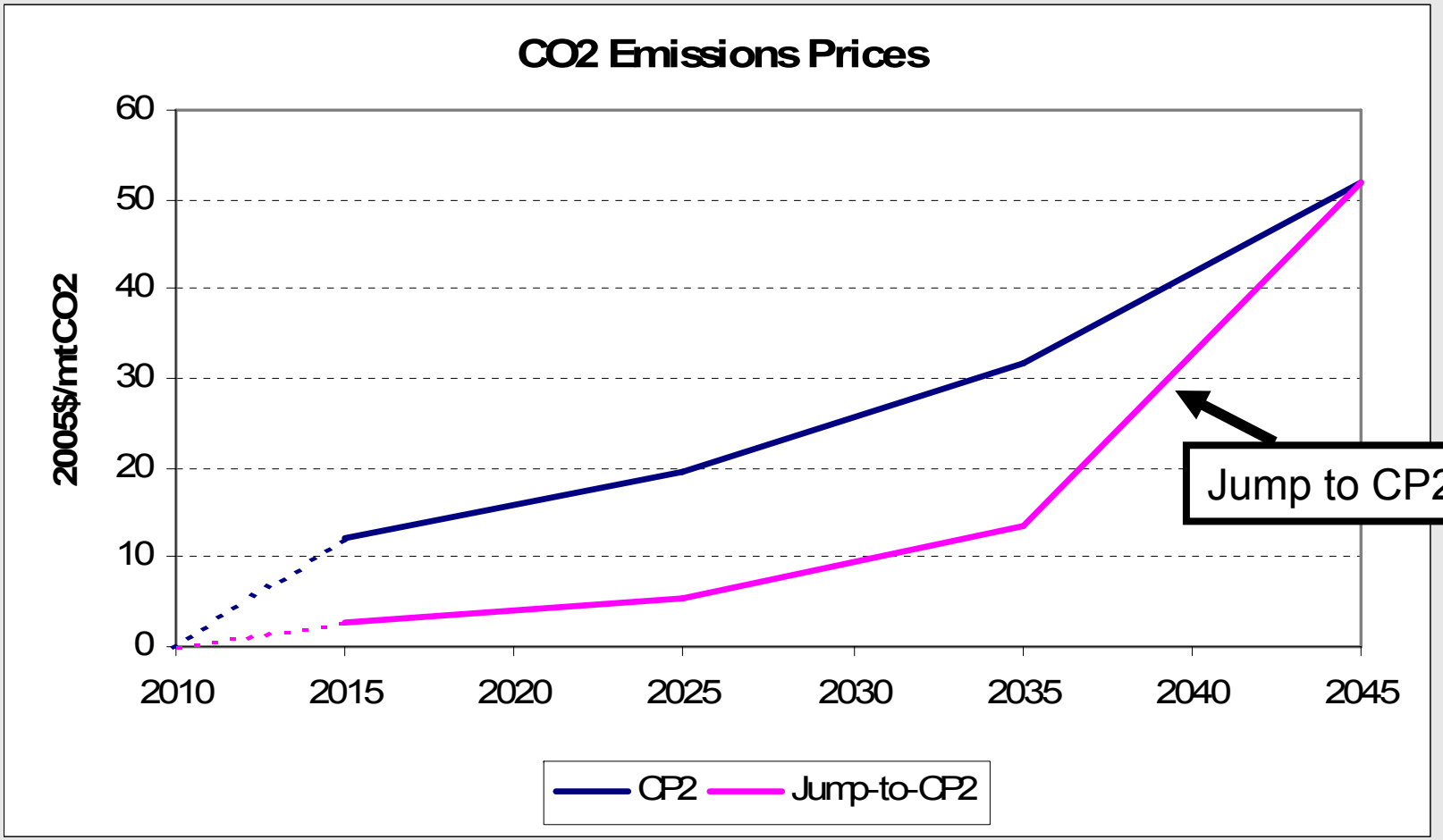

- Under the smooth CP2 path, new builds from now until 2045 are IGCC+CCS (which serves the baseload) and gas CC.
- No new PC capacity is built, and no PC are retrofited with CCS.
- Existing PC capacity is moved behind gas CC in the dispatch order, and much has been or is close to economic retirement .

## Improved PC+CCS, CP2 CO2 Price Path



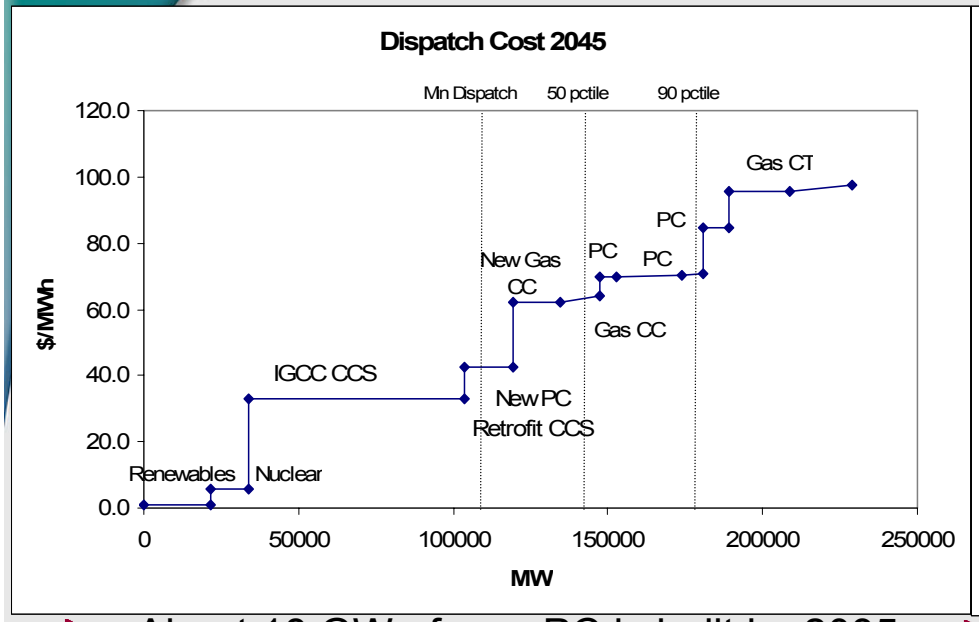

- Under the smooth CP2 path, no new PC or PC+CCS capacity is built even under Improved technology.
- However, about 20 GW of existing PC is retrofited with CCS.
- This retrofit PC+CCS serves partly in baseload and pushes gas back in the dispatch order, lowering off-peak prices.

# Smooth CP2 and Jump to CP2



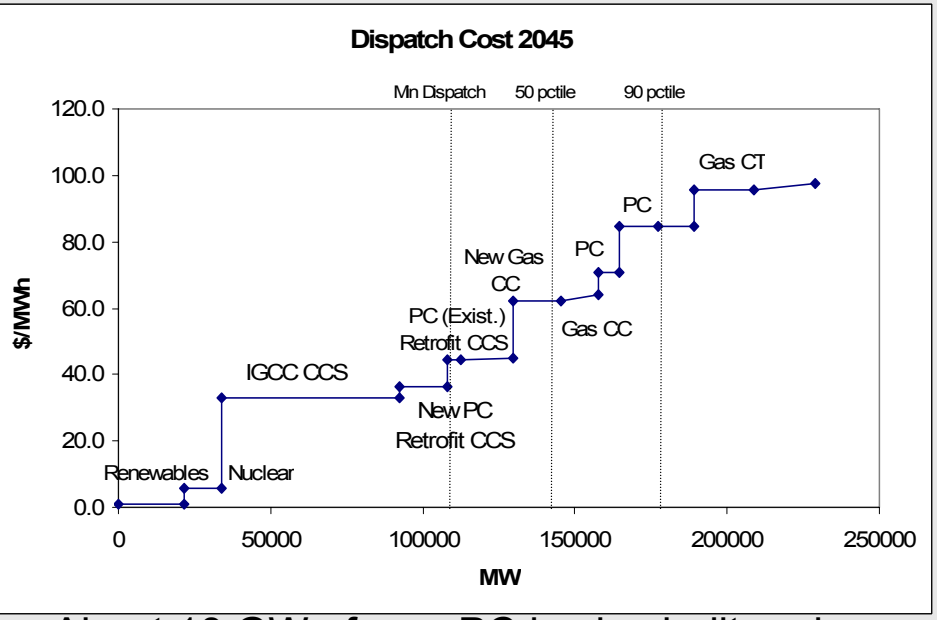
# ECAR 2045: Jump to CP2 $CO_2$ Price Path
# Base vs. Improved PC Capture Technology

## Base PC+CCS, Jump to CP2 CO2 Price Path



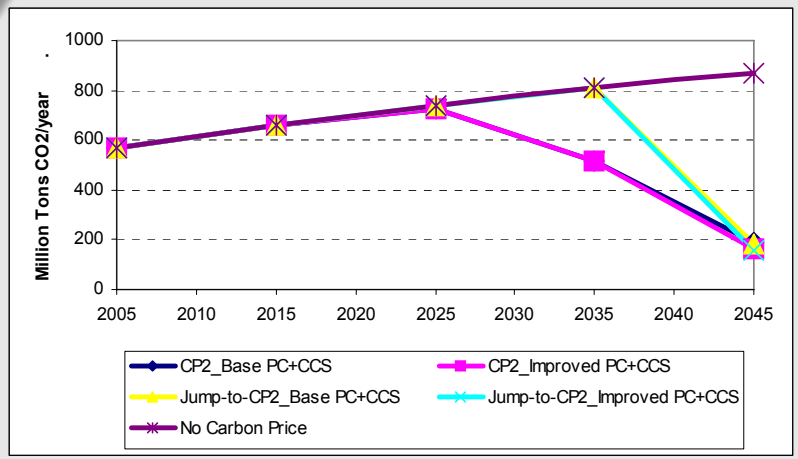

- About 18 GW of new PC is built by 2035, and retrofits to CCS by 2045. IGCC+CCS dominates baseload.
- None of the existing (pre-2007) PC capacity is retrofit.
- Existing PC capacity is moved behind gas CC in the dispatch order, and much has been or is close to economic retirement .

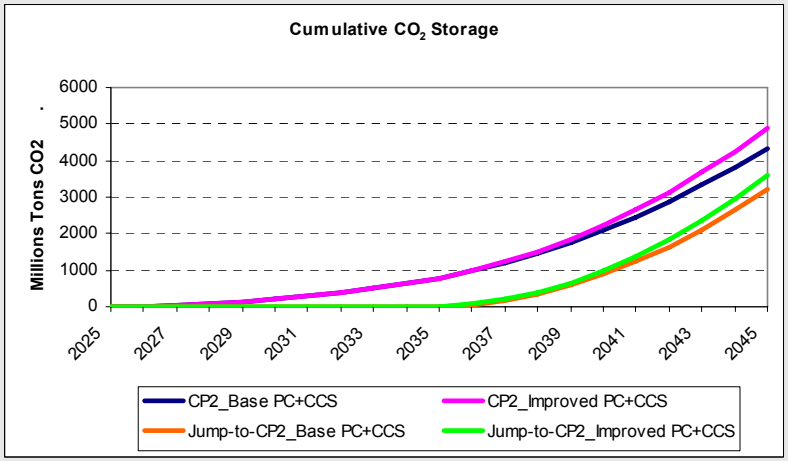
## Improved PC+CCS, Jump to CP2 CO2 Price Path




- About 18 GW of new PC is also built and retrofit to CCS, but here its dispatch cost is lower.
- About 10 GW less IGCC+CCS capacity is built (as PC+CCS serves some baseload).
- Retrofit of new and existing PC+CCS serves partly in baseload and pushes gas back in the dispatch order, lowering off-peak prices.

# ECAR Electric Power Industry Emissions and Demand for $CO_2$ Storage under these Four Scenarios



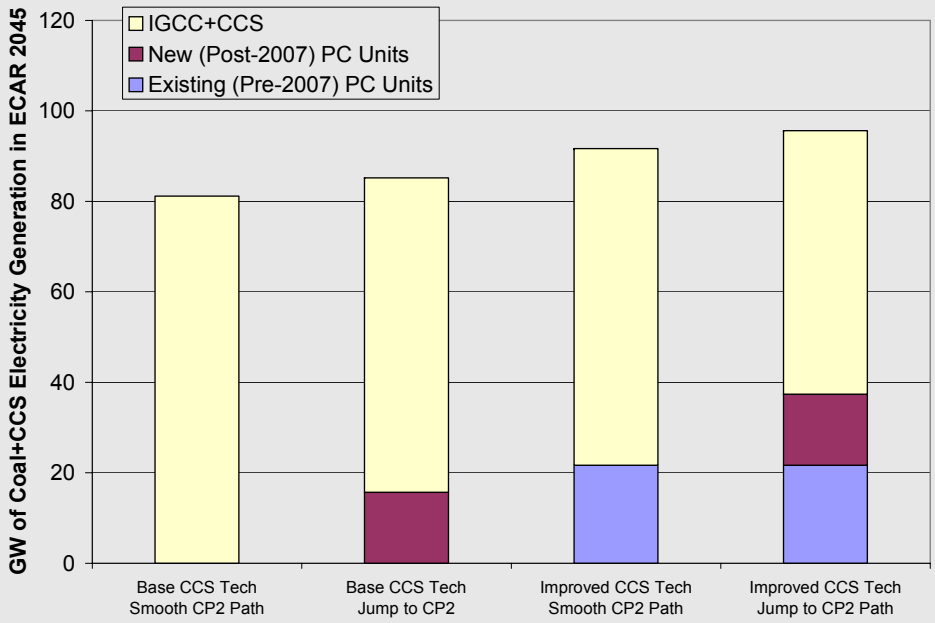




- By 2045 all cases reduce, US electric utility emissions 2/3 from their 2005 levels.
- However, the emissions trajectories differ significantly.

- By 2050, between 3 and 5 billion tons of $CO_2$ could be stored in deep geologic formations within ECAR.
- While less $CO_2$ is cumulatively is stored in the "jump-to-CP2 cases by the middle of the century, all of the storage takes place in less than a decade's time.

# Summary of Results

- Even if technology develops such that new IGCC+CCS is the preferred option advanced PC-based $CO_2$ capture technologies are still likely an important aspect of society's portfolio of responses to addressing climate change.
- Improvements in post-combustion technology
  - are key for allowing economic retrofits of existing capacity.
  - helps lower the societal cost of reducing $CO_2$ emissions, and helps maintain value of existing PC capacity.
  - may be more important in other parts of the world where much new PC is expected to be built in the next decade.
  - (as shown in the "Jump-to-CP2" cases) are a valuable hedge to mitigate the cost of building new capacity under uncertainty of future $CO_2$ policies.



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# Appendix

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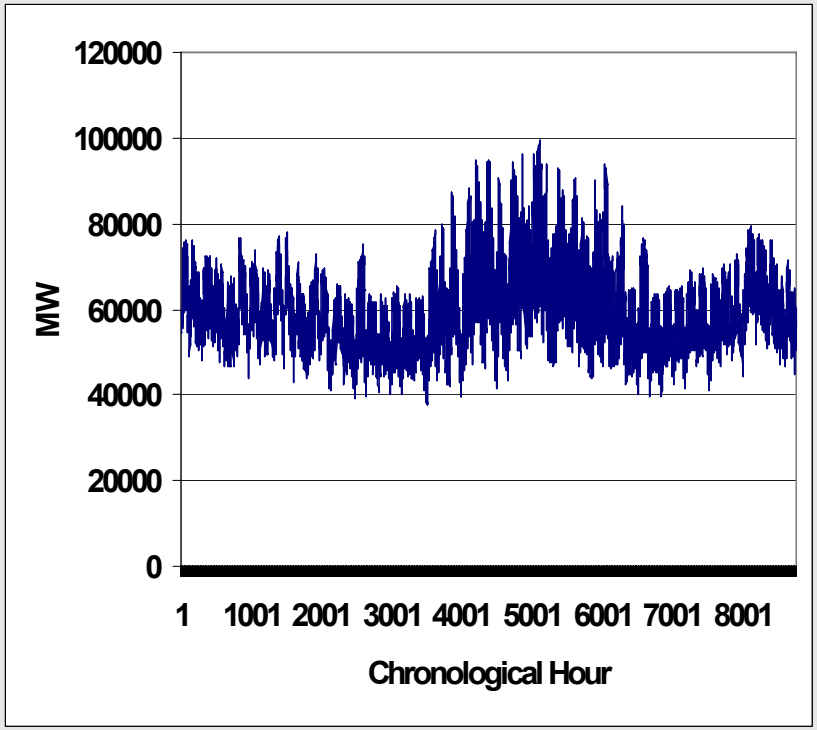
# Electricity Demand and the Load Duration Curve

ECAR 2002 Hourly Demand




ECAR Load Duration Curve (Sorted Hourly Demand)


- Load Duration Curve is a key driver of the economic trade-offs involved in determining the mix of new capacity to be built from baseload to peaking.